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ORIGINAL ARTICLE

Comparison of Centers for Disease Control and Prevention and World Health Organization references/standards for height in contemporary Australian children: Analyses of the Raine Study and Australian National Children's Nutrition and Physical Activity cohorts

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Aim: (i) To compare the Centers for Disease Control and Prevention (CDC) reference and World Health Organization (WHO) standard/reference for height, particularly with respect to short stature and eligibility for growth hormone (GH) treatment by applying them to contemporary Australian children; (ii) To examine the implications for identifying short stature and eligibility for GH treatment.

Methods: Children from the longitudinal Raine Study were serially measured for height from 1991 to 2005 (2–15-year-old girls (660) and boys (702) from Western Australia). In the cross-sectional Australian National Children's Nutrition and Physical Activity survey (2–16-year-old boys (2415) and girls (2379) from all states), height was measured in 2007. Heights were converted to standard deviation scores (SDSs) based on CDC and WHO.

Results: Means and standard deviations of height-SDS varied between CDC and WHO definitions and with age and gender within each definition. However, both identified similar frequencies of short stature (<1st centile for GH eligibility), although these were very significantly less than the anticipated 1% (0.1–0.7%) of the Australian cohorts. Mean heights in the Australian cohorts were greater than both the WHO and CDC means.

Conclusions: Neither CDC nor WHO height standardisations accurately reflect the contemporary Australian child population. Australian children are taller than the CDC or WHO height means, and significantly less than 1% of Australian children are defined as being short using either CDC or WHO. This study suggests there may be a case for an Australian-specific standard/reference for height.

Key words: growth standard; growth reference; paediatric; Raine Study.

What is already known on this topic

1 Height is gender and age dependent. Thus, it is difficult to directly compare heights of children and to define clinically relevant cut-off points such as short stature. Standards/references enable conversion of measurements of height to a standard deviation score (SDS).
2 Both the Centers for Disease Control and Prevention (CDC) and World Health Organization (WHO) produce height references or standards for children but they differ in the philosophies, methods and base populations used to derive them and in the values they contain.
3 There has been considerable debate as to which standard/reference is the most appropriate for use in Australia. Much of this has centred on the philosophies behind each.

What this paper adds

1 This paper assesses the CDC and WHO methods of height standardisation specifically for use by Australian medical practitioners by applying them to two contemporary populations of Australian children aged from 2 to 16 years of age.
2 It specifically considers the clinical implications of using CDC- or WHO-derived height-SDS on the assessment of short stature and the auxological eligibility criterion for growth hormone therapy (<1st centile) in Australia.
3 Mean height-SDS varied between CDC and WHO definitions and with age group and gender. Thus, neither were standardised well and they were discrepant. However, both identified similar frequencies of short stature, although these were less than an anticipated 1% of the Australian cohorts.

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Height growth charts and growth reference data tables are used to monitor an individual child's growth trajectory primarily to identify abnormal growth patterns that may indicate underlying medical or social issues requiring further investigation.[1–3] They are also used in analysis and reporting of population growth data and secular trends[1,2] and, in Australia, in defining eligibility criteria for growth hormone (GH) therapy.[4] The effectiveness of growth monitoring for population-based health screening and surveillance has been questioned[5] following a Cochrane review, which concluded evidence in support or otherwise was scarce.[6,7] However, routine height and weight evaluation of children continues to be a mainstay of individual childhood health assessments. Additionally, growth monitoring is recommended as a minimum in Australian indigenous communities because of high rates of growth failure.[1] It is important, therefore, that clinicians understand how growth charts and reference data perform when applied to Australian populations.

Growth is gender and age dependent. Hence, to enable meaningful comparisons between individuals of different ages or genders, the Centers for Disease Control and Prevention (CDC)[8] and World Health Organization (WHO)[9,10] produce growth standards/references. These 'standardise' measurements of height by converting each gender/age-specific distribution of heights to a standard normal distribution with mean 0 and standard deviation (SD) 1. A particular height can then be expressed as the number of SDs from the mean, the standard deviation score (SDS), or equivalently as a centile, the percentage of heights that are shorter than that height. The CDC and WHO differ in the philosophies and methods used to derive their reference or standard and in the values they produce. Briefly, the CDC is derived from measurements of US children collected from 1963 to 1994 and is referred to as a 'reference'.[11] The WHO values, conversely, aim to reflect optimal growth. Children, 0–5.9 years of age, growing in optimal environments were sampled from Brazil, Ghana, India, Norway, Oman and the United States and as such are referred to as a standard.[9] For older children and adolescents, the WHO reconstructed the National Center for Health Statistics/WHO growth reference from 1977 (a non-obese sample) using advanced statistical methods that also enabled a smooth merging of the two samples.[10]

There has been considerable debate as to which standard/reference is the most appropriate and much of this has centred on the philosophies behind each.[1,12–21] The practical application of the two standardising formats has also been addressed by Mei and co-workers in children from the United States with respect to short stature (<5th centile, 0–59 months)[16] or proportion crossing ≥2 major height-percentile lines (0–24 months).[13] Recently, Yasin and Filler compared CDC and WHO for height and weight standardisation in a contemporary paediatric population of 0–5-year-old Canadian children.[22] Our primary aim, therefore, was to assess the CDC and WHO methods of height standardisation specifically for use by Australian medical practitioners by applying them to two contemporary populations of healthy Australian children aged 2 to 16 years of age. Currently, the National Health and Medical Research Council (NHMRC) recommends WHO growth charts for children aged 0–2 years, but CDC charts are also in common use.[23] We specifically consider the clinical implications of using CDC, as is the case currently,[4] or WHO-derived height-SDS in identifying children shorter than the first height centile as this is the auxological eligibility criterion for GH therapy in Australia.[4]

Methods

Participants

Raine Study cohort

The Western Australian Pregnancy (Raine) Study cohort is one of the largest and most closely followed prospective cohorts in the world.[24] Recruitment has previously been described in detail.[24,25] In brief, from 1989 to 1991, 2900 pregnant women from Perth, Western Australia were enrolled in the study between 16 and 20 weeks gestation. They delivered 2868 live-born children. The analyses in this study were based on 1362 (660 female, 702 male) Raine Study children who met the criteria of live, unrelated, singleton births, with no congenital abnormalities who attended for regular follow-up. The last data presented here were collected in 2005 from 13- to 14-year-old children. Protocols for the study were approved by the human research ethics committees at the King Edward Memorial Hospital and/or Princess Margaret Hospital for Children in Perth, Western Australia.

2007 Australian National Children's Nutrition and Physical Activity survey

The Australian National Children's Nutrition and Physical Activity (ANCNPA) survey included 2415 boys and 2379 girls aged 2–16 years from all states and territories of Australia.[26] An initial target quota of 1000 children (50% boys and 50% girls) for each age group (2.00–3.99 years, 4.00–8.99 years, 9.00–13.99 years and 14.00–16.99 years) was set. This was supplemented in South Australia to allow more detailed estimates for that state. Households with children aged 2–16 years were selected using random digit dialing from all Australian states and territories such that metropolitan, rural and remote areas were included. The number of children included from each state was proportional to the population of children in that state.[26] These data were accessed with permission from the Australian Social Sciences Data Archive (http://assda.anu.edu.au/).

Analyses

CDC- and WHO-derived height-SDS values were compared across ages and genders, with respect to the mean and first centile of each. The first height centile, equivalent to an SDS value of −2.33, is the value chosen by the Australian government for eligibility for GH treatment of short stature.[4]

Heights were converted to SDS values using CDC[8] and WHO[9] data tables and the LMS method.[27] L (power of the Box-Cox transformation), M (median) and S (generalised coefficient of variation) values are provided for each age and gender in the CDC[8] and WHO[9] data tables.

Means and SDs of height-SDS were calculated for each cohort-gender-age group combination and for the whole of each cohort for each gender. Percentages falling below the f centile were also calculated for these groups. The CDC and WHO converted distributions of height in their base populations to

Table 1 Mean height-SDS

Age (years)	Gender	Raine	Mean†‡		ANCNPA	Mean†‡		ANCNPA All§			Mean†‡	
		n	CDC	WHO	*n*	CDC	WHO	Age (years)	Gender	*n*	CDC	WHO
1.93–2.60	Female	ND¶	ND¶	ND¶	139	∧–0.01^{A}	0.01^{A}	2.0–4.49	Female	634	0.27^{C}	0.04^{C}
2.92–3.50	Female	458	∨0.25^{C}	∨–0.06^{C}	177	0.36^{C}	0.06^{C}	4.5–6.99	Female	291	0.34^{C}	0.20^{C}
5.50–6.60	Female	593	∨0.24^{C}	∨0.17^{C}	115	0.33^{C}	0.30^{C}	7.0–9.49	Female	323	0.22^{C}	0.37^{C}
7.40–8.80	Female	596	∨0.07^{a,a,C}	∨0.26^{a,C}	181	∧0.26^{a,C}	0.44^{a,C}	9.5–11.99	Female	311	0.34^{C}	0.27^{a,C}
10.30–11.00	Female	568	∨0.36^{C}	0.24^{b,C}	85	0.31^{C}	0.18^{a,C}	12.0–14.49	Female	362	0.28^{C}	0.35^{C}
13.40–14.60	Female	649	0.40^{C}	∨0.46^{C}	195	0.26^{C}	0.33^{C}	14.5–16.99	Female	458	0.45^{a,A}	∧0.45^{A}
All	Female	2864	∨0.27^{C}	∨0.23^{a,C}	892	0.25^{C}	0.23^{C}	All	Female	2379	0.32^{C}	0.26^{C}
1.93–2.60	Male	ND¶	ND¶	ND¶	158	0.08	0.09	2.0–4.49	Male	700	0.26^{C}	0.10^{C}
2.92–3.50	Male	453	0.28^{C}	0.01^{C}	184	0.34^{C}	0.10^{C}	4.5–6.99	Male	287	0.45^{C}	0.33^{C}
5.50–6.60	Male	632	0.31^{C}	0.20^{C}	129	0.43^{C}	0.33^{C}	7.0–9.49	Male	305	0.22^{C}	0.35^{C}
7.40–8.80	Male	622	0.19^{a,C}	0.32^{C}	185	0.32^{C}	0.46^{C}	9.5–11.99	Male	298	∨0.38^{C}	0.48^{a,C}
10.30–11.00	Male	601	0.30^{C}	0.42^{b,C}	74	0.47^{C}	0.58^{a,C}	12.0–14.49	Male	334	0.37^{C}	∨0.43^{C}
13.40–14.60	Male	687	∧0.40^{C}	∧0.48^{C}	210	0.32^{C}	0.41^{C}	14.5–16.99	Male	491	0.32^{a,C}	0.38^{C}
All	Male	2995	∧0.30	∧0.30^{a}	940	0.31	∧0.31	All	Male	2415	0.32^{C}	0.31^{C}

†Mean height-SDS. Underlined height-SDS means do not differ significantly ($P < 0.05$) from 0. ‡Standard deviations of height-SDS are not shown as most lie close to 1.0. However, symbols ∧ or ∨ indicate the standard deviation is significantly ($P < 0.05$) greater than or less than 1.0, respectively. §Utilising heights from all children in the ANCNPA study. Divided into six age groups (not used for comparison to Raine). ¶Raine 2-year-olds' heights were measured in supine position and thus, were not used for comparisons. Statistical significance of comparisons within age groups: A, B, C refer to comparisons between CDC and WHO within cohort and gender; a, b, c refer to comparisons between Raine and ANCNPA cohorts; a, b, c refer to comparisons between genders within cohorts. a: $0.05 > P > 0.01$; b: $0.01 > P > 0.001$; c: $P < 0.001$. ANCNPA, Australian National Children's Nutrition and Physical Activity; CDC, Centers for Disease Control and Prevention; ND, no data; SDS, standard deviation score; WHO, World Health Organization.

standard normal distributions with mean = 0 and SD = 1. A one-sample *t*-test was used to test the hypothesis that the mean height-SDS of the Australian cohorts was also equal to 0. The chi-square test for variance was used to test that the SDs of the Australian height-SDSs were equal to 1. Paired *t*-tests were used to compare CDC and WHO height-SDS means. Two sample *t*-tests were used for comparisons of means between the Raine Study and ANCNPA cohorts or genders. Analysis of variance (ANOVA) or repeated measures ANOVA (Raine Study) were used to test if means varied significantly between age groups. Chi-square tests were used to compare frequencies of short stature between CDC and WHO, standardising protocols, cohorts or genders. Statistical tests were performed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) or SPSS 17.0 (SPSS, Inc., Chicago, IL, USA).

The Raine Study children were measured six times after birth resulting in six age groups as presented in Table 1. In this study, we refer to these groups as 2-year-olds (measured in 1991–1992), 3-year-olds (1993–1994), 6-year-olds (1995–1998), 8-year-olds (1998–1999), 10-year-olds (2000–2002) and 14-year-olds (2003–2005). Comparisons between Raine Study and ANCNPA for height-SDS were performed on equivalent age groups in the ANCNPA. ANCNPA measurements were all carried out in 2007. The whole ANCNPA population (ANCNPA All) was also used in analyses when not being compared with the Raine cohort. In this instance, six contiguous age groups were constructed so as to conform to the structure of Tables 1 and 2. The whole ANCNPA population was also used in plotting moving means to give a continuous visual interpretation of how height-SDS means change with age (Fig. 2).

The majority of the Raine Study 2-year-olds' 'heights' were measured in a supine position. ANCNPA children in this age group and all other age groups for both cohorts were measured standing. Because of these differences, comparisons involving the Raine Study 2-year-olds were not performed.

Results

Comparison of CDC and WHO height curves

The CDC and WHO height growth curves are very similar. However, Figure 1 highlights, in particular, the differences between heights defined as being at the first centile under each standardising protocol. It can be seen that the CDC and WHO first centile heights can differ by as much as 2 cm with either being the shortest depending on age.

Mean height-SDS of Australian cohorts

1 *Comparison to Expected Mean of 0:* Mean heights of Raine Study and ANCNPA cohorts in terms of CDC- and WHO-derived SDS are shown in Figure 2 and Table 1. Mean height-SDSs were, in general, significantly greater than 0 (range $P = 0.015$ for WHO ANCNPA All male 2.0–4.49 year olds to $P = 1.2 \times 10^{-53}$ for CDC Raine total males) for both cohorts under both CDC and WHO. However, some of the mean height-SDSs of the younger age groups, particularly when using the WHO-derived SDS, were not significantly different from 0 as shown in Table 1 (underlined means).

Table 2 Percentage of children shorter than first centile

Age	Gender	Raine			ANCNPA			ANCNPA All†			% shorter than first centile	
		n	% shorter than first centile		*n*	% shorter than first centile				*n*		
			CDC	WHO		CDC	WHO	Age	Gender		CDC	WHO
1.93–2.60	Female	ND‡	ND‡	ND‡	139	0.72	1.44	2.0–4.49	Female	634	0.47	0.79
2.92–3.50	Female	458	0.22	0.44	177	0.00	0.56	4.5–6.99	Female	291	0.69	0.69
5.50–6.60	Female	593	0.34	0.51	115	0.00	0.00	7.0–9.49	Female	323	0.62	0.31
7.40–8.80	Female	596	1.17	0.34	181	0.00	0.00	9.5–11.99	Female	311	0.00	0.00
10.30–11.00	Female	568	0.18	0.53	85	0.00	0.00	12.0–14.49	Female	362	0.28	0.28
13.40–14.60	Female	649	0.62	0.31	195	0.00	0.00	14.5–16.99	Female	458	0.00	0.00
Total%	Female	2864	0.52	0.42	892	0.11	0.34		Female	2379	0.34	0.38
1.93–2.60	Male	ND‡	ND‡	ND‡	158	0.63	0.63	2.0–4.49	Male	700	0.86	1.00
2.92–3.50	Male	453	0.88	1.55	184	1.09	1.63	4.5–6.99	Male	287	0.35	0.35
5.50–6.60	Male	632	0.32	0.47	129	0.00	0.00	7.0–9.49	Male	305	0.98	0.98
7.40–8.80	Male	622	0.64	0.32	186	0.54	0.54	9.5–11.99	Male	298	0.00	0.00
10.30–11.00	Male	601	0.33	0.17	74	0.00	0.00	12.0–14.49	Male	334	0.60	0.60
13.40–14.60	Male	687	0.58	0.87	210	0.48	0.48	14.5–16.99	Male	491	0.81	0.81
Total%	Male	2995	0.53	0.63	940	0.53	0.63		Male	2415	0.66	0.70

†Utilising heights from all children in the ANCNPA study and divided into six age groups. Not compared to the Raine Study. ‡Raine 2-year-olds' heights were measured in supine position and thus, were not directly comparable. a, b, c: a: $0.05 > P > 0.01$; b: $0.01 > P > 0.001$; c: $P < 0.001$. A, B, C refer to comparisons between CDC and WHO within cohort and gender; a, b, c refer to comparison between Raine and ANCNPA cohorts; a, b, c refer to comparison between genders within cohorts. ANCNPA, Australian National Children's Nutrition and Physical Activity; CDC, Centers for Disease Control and Prevention; ND, no data; WHO, World Health Organization.

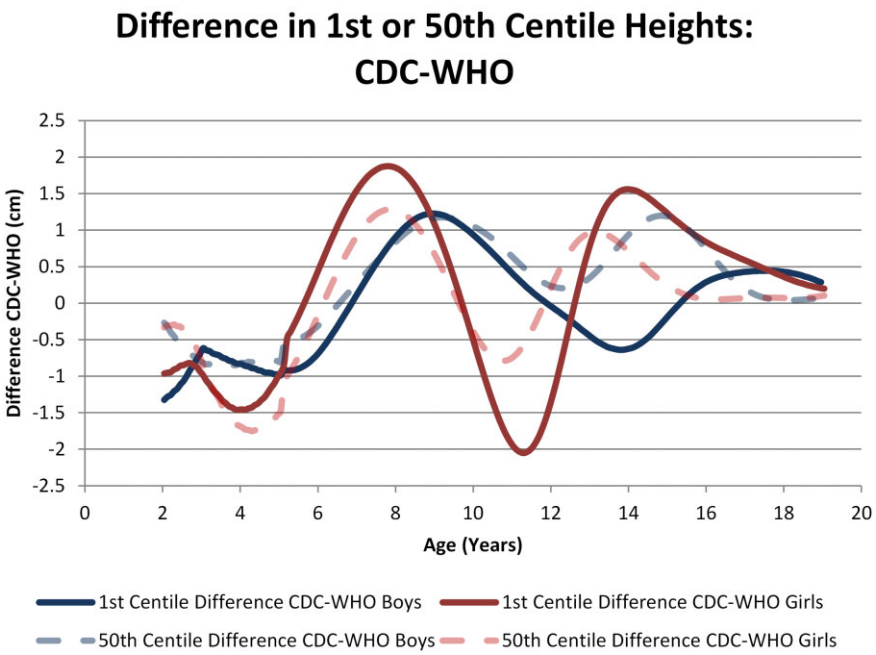

Fig. 1 Comparison of CDC and WHO 50th and 1st centile heights with respect to age and gender. CDC, Centers for Disease Control and Prevention; WHO, World Health Organization.

2 *Effect of Age Group:* Means varied significantly with age group. This was most apparent for the Raine cohort using WHO (female $P = 4.4 \times 10^{-62}$, male $P = 1.8 \times 10^{-30}$) and least for the ANCNPA using CDC (female $P = 0.017$, male $P = 0.034$).

3 *Comparison between CDC and WHO:* For almost all age groups in both cohorts, CDC and WHO means were significantly different from each other (Table 1; range $P = 0.0001$ to $P < 10^{-254}$). The exceptions were ANCNPA male ($P = 0.51$) and female ($P = 0.026$) 2-year-olds and ANCNPA-All 15-year-old

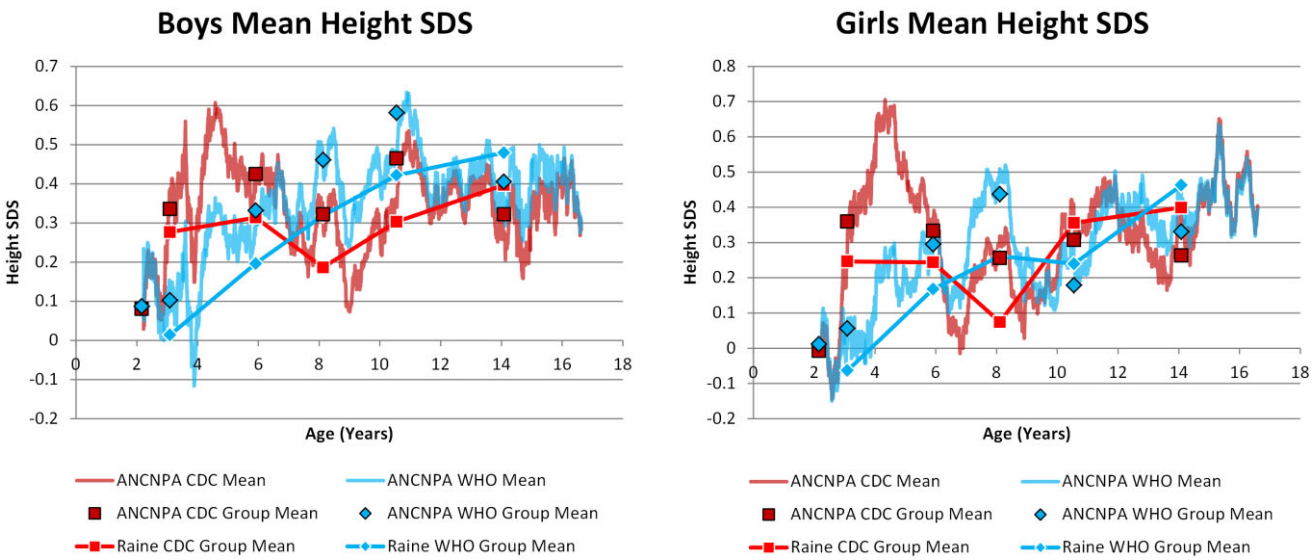

Fig. 2 Mean height SDS in Raine and ANCNPA cohorts.
Curves represent moving means of 100 individuals ordered by age, that is, the mean height SDS of the youngest 100 individuals is found and plotted at their median age. The 100 individuals then 'move', dropping the youngest, but now including the 101st youngest. The mean is found in this new group and plotted as before. The 100 continue moving until it contains the oldest 100 individuals. Symbols represent the mean of the age groups defined in the methods. ANCNPA, Australian National Children's Nutrition and Physical Activity; CDC, Centers for Disease Control and Prevention; SDS, standard deviation score; WHO, World Health Organization.

girls ($P = 0.047$). For both cohorts and in both genders, the CDC mean height-SDS was greater than the WHO mean height-SDS from approximately 2 to 7 years of age but from 7 to at least 14 years, the WHO mean was seen to be greater (Fig. 2).

4 *Comparison between Cohorts:* The ANCNPA 8-year-old girls were taller than their Raine Study counterparts using both CDC and WHO standardisations. No other significant differences were noted (Table 1).
5 *Comparison between Genders:* A number of significant differences in mean height-SDS were seen between genders in both cohorts (Table 1). Such differences were seen for both CDC and WHO but never together in the same age group.

SDs of height-SDS in Australian cohorts

SDs of height-SDS are not shown in Table 1, but any SD significantly different from 1.0 is indicated. Raine cohort female SDs were, in general, significantly less than 1.0 under both CDC and WHO. Overall, the Raine males SDs were significantly greater than 1.0 under both CDC and WHO. For WHO-derived SDSs, the ANCNPA males overall had SDs significantly greater than 1.0.

Short stature

A height equivalent to the first centile of the CDC reference is the cut-off used in Australia to define short stature and eligibility for GH treatment.[4] Table 2 compares the percentages of children shorter than the first centile according to CDC and WHO standardisations. No significant differences were identified. CDC and WHO identified a similar proportion of children (all age groups combined) shorter than the first centile in both Raine and ANCNPA cohorts. However, for both cohorts under both standards, there were significantly fewer than 1% of children identified as being shorter than the first centile (Raine and ANCNPA combined; $P_{CDC} = 5.1 \times 10^{-7}$, $P_{WHO} = 1.4 \times 10^{-6}$).

Discussion

This study has demonstrated that neither CDC nor WHO growth charts effectively standardised height in two large independent Australian childhood cohorts and that they consistently underdiagnosed short stature in these cohorts. Currently, in the absence of Australian-specific growth standards, the NHMRC[23] (and CDC[28]) recommends that WHO standards be used for children younger than 2 years. Our comparisons were thus restricted to children older than 2 years. The question over which of WHO or CDC height standardisations should be used has generated considerable debate,[1,5,12–18,20,22] but the results of this study would suggest, with respect to practical height monitoring in Australia, that the development and use of local growth charts certainly be considered.

The aim of using a height standard/reference is to allow meaningful comparisons between individuals or populations of different ages and genders and to provide suitable clinical cut-offs to identify children with clinically significant short stature. Thus, once standardised, one should expect means and SDs to be the same across age groups and between genders. If the Australian populations under investigation grow similarly to the populations used to construct the CDC or WHO reference/standards, a mean of 0 and an SD of 1 is also expected for height-SDS values.

The CDC and WHO height curves differ between each other with age and gender (Fig. 1). When applied to two contemporary Australian cohorts, significant differences were clearly evident between mean height-SDS derived from CDC or WHO for almost all age group/gender/cohort combinations (Table 1 and Fig. 2). For both cohorts and genders, the CDC mean height-SDS was greater than the WHO mean height-SDS from approximately 2 to 7 years of age (Fig. 2). This is consistent with the findings of Mei *et al.*[16] and Yasin and Filler[22] for US and Canadian populations of 0–5 years old, respectively. However, from 7 to at least 14 years, the WHO mean was seen to be greater (Fig. 2). It was also evident that, far from standardising heights across ages and genders, mean height-SDS varied considerably between age groups and genders within both CDC- and WHO-derived values. Similar observations were reported by Yasin and Filler[22] for 0–5-year-old Canadian children. Also, CDC- and WHO-derived height-SDS means were greater than 0 for both cohorts and genders and all age groups, indicating that Australian children are taller than both the CDC and WHO reference populations. This is likely due to the secular trend in height as both CDC and WHO (>5 years of age) reference populations were sampled 20 to 50 years ago.[10,11,29] SDs were often either significantly greater than or significantly less than 1. As height-SDS means and SDs often varied significantly between age groups and genders and from 0 and 1, respectively, we conclude that neither CDC nor WHO adequately 'standardise' heights of Australian children. Having said this, clinically significant growth failure of an Australian child should be readily identifiable using either chart as a template.

Given the differences in means, it might be expected that CDC and WHO would identify significantly different numbers of children falling below the first centile, the essentially arbitrary criterion used to define short stature by the Australian Department of Health. Yasin and Filler[22] warned of this possibility following the results of their study while Mei *et al.* found a higher prevalence of 'short stature' (<5th centile) for all age groups from 0 to 5 years when WHO rather than CDC height charts were used.[16] However, in this study, although percentages falling below the first centile often differed between CDC and WHO within age groups, no differences reached significance, given our sample sizes. Indeed, across all 2–16-year-olds, the WHO and CDC identified very similar percentages of short children. Importantly however, this percentage was always significantly less than the anticipated 1% and varied between 0.1 and 0.7% when age groups were combined (Table 2).

The clinical implications and significance of these observations are that neither CDC nor WHO height standardisations accurately reflect the contemporary Australian child population. These results suggest a need for an Australian-specific height reference/standard and are likely to raise debate as to the definition of short stature and GH eligibility on auxological criteria.

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Russian dolls by Lilia Jackson (13) from Operation Art 2011.